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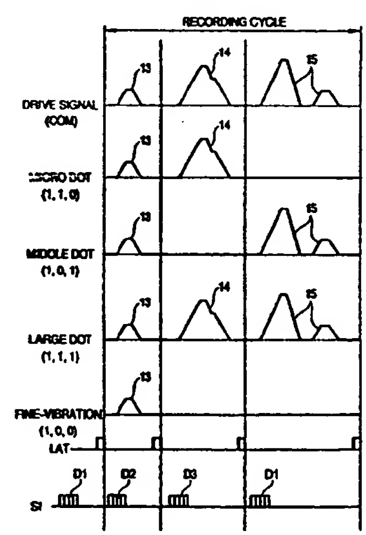
(54) Ink jet recording apparatus

(57) A drive signal generator generates a drive signal including a first waveform component for jetting an ink drop to be a micro dot and a second waveform component for jetting an ink drop to be a middle dot. A pressure generating element varies the volume of a pressure generating chamber in accordance with the drive signal to jet an ink drop from a nozzle orifice. An ink drop to be a large dot is jetted from the nozzle orifice when the first waveform component and the second waveform component are consecutively applied to the pressure generating element. A time interval $T\mu m$ between an end point of the first waveform component and a start point of the second waveform component is set so as to substantially satisfy the following equation:

$$T\mu m = \frac{n}{2} Tc$$

here, Tc denotes a natural period of the pressure generating chamber.

FIG. 6



nal including a first waveform component for jetting an ink drop to be a micro dot and a second waveform component for jetting an ink drop to be a middle dot;

a pressure generating chamber communicated with a nozzle orifice; and

a pressure generating element for varying the volume of the pressure generating chamber in accordance with the drive signal to jet an ink drop from the nozzle orifice.

[0018] An ink drop to be a large dot is jetted from the nozzle orifice when the first waveform component and the second waveform component are consecutively applied to the pressure generating element.

[0019] When a frequency distribution of occurring a recording failure increases periodically as a function of a time interval Tμm between an end point of the first waveform component and a start point of the second waveform component, an actual Tμm is so as to avoid a value of which the frequency distribution increases.

[0020] In these apparatuses, the drive signal includes a third waveform component applied to the pressure generating element prior to the application of the first waveform component in order to finely vibrate a meniscus of the ink in the nozzle orifice.

[0021] Preferably, a time interval between an end point of the third waveform element and a start point of the first waveform element is set as a period in which the vibration caused by the third waveform element attenuates sufficiently.

[0022] Accordingly, jetting an ink drop by the first waveform component can be stabilized.

[0023] In these apparatuses, the pressure generating element is a piezoelectric vibrator formed into a comb-teeth shape in which electrodes and a piezoelectric body are laminated in a direction orthogonal to a deforming direction thereof.

[0024] Here, the time interval between the end point of the first waveform component and the start point of the second waveform component is not less than 3Tc.

[0025] Accordingly, recording failures can be prevented more effectively.

[0026] In order to attain the same effect, there is also provided an ink jet recording apparatus comprising:

a drive signal generator for generating a drive signal including a first waveform component for jetting an ink drop to be a micro dot and a second waveform component for jetting an ink drop to be a middle dot;

a pressure generating chamber communicated with a nozzle orifice; and

a pressure generating element for varying the volume of the pressure generating chamber in accordance with the drive signal to jet an ink drop from the nozzle orifice,

wherein an ink drop to be a large dot is jetted from the nozzle orifice when the first waveform component and the second waveform component are consecutively applied to the pressure generating element, and

wherein a time interval between an end point of the first waveform component and a start point of the second waveform component is set so as to avoid ink ejection error.

[0027] Here, the time interval is represented as a function of a natural period of the pressure generating chamber.

[0028] Embodiments of the present invention will now be described by way of further example only and with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagram showing the configuration of an ink jet printer;

Fig. 2 is a perspective view showing the internal mechanism of the ink jet printer;

Fig. 3 is a sectional view showing the structure of a recording head;

Fig. 4 is a diagram showing an equivalent circuit for explaining characteristic vibration of ink in a cavity;

Fig. 5 is a block diagram showing the electric configuration in the recording head;

Fig. 6 is a diagram showing the relationship between drive signals and recording dots;

Fig. 7 is a diagram showing the drive signals;

Fig. 8 is a table showing evaluation of the record results when patterns are recorded while the time interval between the micro dot waveform and the middle dot waveform, Tμm, is changed; and

Figs. 9A to 9D are diagrams showing record patterns for evaluation, namely, a one-line jetting pattern, a three-line jetting pattern, an alternate jetting pattern, and a one-line omission pattern, respectively.

[0029] Referring now to the accompanying drawings, there is shown an embodiment of the invention by taking an ink jet printer (simply, printer) of a representative ink jet recording apparatus as an example. As shown in Fig. 1, the printer is roughly made up of a printer controller 1 and a print engine 2.

[0030] The micro dot, middle dot, and large dot throughout the specification represent dots having ink weight increased for forming the dots in the order of the micro dot, middle dot, and large dot.

[0031] The printer controller 1 comprises an external interface 3 (external I/F 3), RAM (random access memory) 4 for temporarily storing various pieces of data, ROM (read-only memory) 5 for storing a control program, etc., a controller 6 containing a CPU (central processing unit), etc., an oscillator 7 for generating a clock signal, a drive signal generator 9 for generating a drive signal (COM) supplied to a recording head 8, and an internal interface 10 (internal I/F 10) for transmitting

member formed with a plurality of cavities (pressure generating chambers) 4 communicating with a plurality f the nozzle orifices 16 formed in the nozzle plate 43 and partitioned by a pressure generating chamber diaphragm and an elongated common ink reservoir 47 with which a plurality of ink supply ports 46 each communicating with at least one end of each cavity 45 communicate. In the embodiment, the common ink reservoir 47 is formed by etching a silicon wafer, the cavities 45 are formed matching the pitches of the nozzle orifices 16 along the longitudinal direction of the common ink reservoir 47, and the groove-like ink supply ports 46 are formed between the cavities 45 and the common ink reservoir 47. The ink supply port 46 is connected to one end of the cavity 45 and the nozzle orifice 16 is positioned in the proximity of the end part on the opposite side to the ink supply port 46. The common ink reservoir 47 is a chamber for supplying ink stored in the ink cartridge 24 to the cavities 45, and an ink supply tube 48 communicates almost at the center in the longitudinal direction.

[0049] The elastic plate 44 is deposited on an opposite face of the channel formation plate 44 positioned on the opposite side to the nozzle plate 43 and is of a double structure comprising a polymer film of PPS, etc., laminated as an elastic film 50 on a stainless plate 49. The stainless plate 49 of the portion corresponding to the cavity 45 is etched to form an island portion 51 for abutting and fixing the piezoelectric vibrator 35.

[0050] In the described recording head 8, the piezoelectric vibrator 35 is expanded in the longitudinal direction of the vibrator, whereby the island portion 51 is pressed against the nozzle plate 43, the elastic film 50 surrounding the island portion 51 becomes deformed, and the cavity 45 is contracted. If the piezoelectric vibrator 35 is contracted in the longitudinal direction of the vibrator, the volume of the cavity 45 is expanded due to elasticity of the elastic film 50. Expansion and contraction of the volume of the cavity 45 are controlled, whereby an ink drop is jetted through the nozzle orifice 16.

[0051] The characteristic vibration of ink in the cavity 45 in the described recording head 8 can be represented by an equivalent circuit shown in Fig. 4. It is known that characteristic vibration cycle Tc of ink in the cavity 45 can be calculated according to the following expression:

$$Tc = 2\pi\sqrt{\frac{Mn \cdot Ms}{Mn+Ms}C}$$

where symbol M denotes inertance of the mass of a medium per unit length [Kg/m^4], symbol Mn denotes inertance in the nozzle orifice 16, symbol Ms denotes inertance in the ink supply port 46, and symbol C denotes compliance of the cavity 45 (pressure generating chamber) [m^5/N].

[0052] The characteristic vibration cycle Tc of ink in the cavity 45 calculated based on the expression is about 8 μsec in the embodiment.

[0053] Next, the electric configuration of the recording head 8 and control for jetting ink drops will be discussed.

[0054] As shown in Fig. 11 the recording head 8 comprises a shift register. 54, a latching circuit 55, a level shifter 56, a switching circuit 57, the above-described piezoelectric vibrator 35, etc. Further, as shown in Fig. 5, the shift register 54, the latching circuit 55, the level shifter 56, the switching circuit 57, and the above-described piezoelectric vibrator 35 consist of shift register elements 54A to 54N, latch elements 55A to 55N, level shifter elements 56A to 56N, switch elements 57A to 57N, and piezoelectric vibrators 35A to 35N, respectively, provided in a one-to-one correspondence with the nozzle orifices 16 of the recording head 8.

[0055] To jet ink drops through the recording head 8, first the controller 6 transmits print data (SI) in series starting at the most significant bit from the output buffer 4C and sets the data in the shift register elements 54A to 54N in sequence in synchronization with a clock signal (CK) from the oscillator 7. If the print data as much as all nozzle orifices 16 is set in the shift register elements 54A to 54N, the controller 6 outputs a latch signal (LAT) to the latching circuit 55, namely, the latch elements 55A to 55N at a predetermined timing. According to the latch signal, the latch elements 55A to 55N latch the print data set in the shift register elements 54A to 54N. The latched print data is supplied to the level shifter 56, a voltage amplifier, namely, the level shifter elements 56A to 56N.

[0056] For example, if the print data is "1," each level shifter element 56A-56N boosts the print data to a voltage value at which the switching circuit 57 can be driven, for example, several ten volts. The boosted print data is applied to the switching circuit 57, namely, the switch element 57A-57N, which then enters a connection state as the print data is applied. For example, the print data is "0" the corresponding level shifter element 56A-56N does not boost the print data. A drive signal (COM) from the drive signal generator 9 is applied to each switch element 57A-57N and when the switch element 57A-57N enters a connection state; the drive signal is supplied to the piezoelectric vibrator 35A-35N connected to the switch element 57A-57N.

[0057] If the drive signal is applied based on the most significant bit data, subsequently the controller 6 transmits the second most significant bit data in series and sets the data in the shift register element 54A-54N. If the data is set in the shift register element 54A-54N, the controller 6 applies a latch signal, thereby latching the set data, and supplies a drive signal to the piezoelectric vibrator 35A-35N. After this, the same operation is repeated to the least significant bit while the print data is shifted to the low-order bit one bit at a time.

[0058] Thus, in the described printer, whether or not

element 73 for holding the GND level V0 for a given time, a fourth charge element 74 for increasing voltage at a constant gradient from the GND level V0 to second intermediate potential V5, a sixth hold element 75 for holding the second intermediate potential V5 for a given time, and a fifth discharge element 76 for decreasing voltage at a constant gradient from the second intermediate potential V5 to the GND level V0.

[0070] In the embodiment, setting is executed for each head so that the ink weight of a large dot jetted by applying the micro dot waveform 14 and the middle dot waveform 15 consecutively becomes 20 ng with respect to potential difference VHM between the middle drive potential V4 and the GND level V0. Potential difference Vsp between the second intermediate potential V5 and the GND level V0 is set based on the potential difference VHM, specifically, is set to 20% of the potential difference VHM.

[0071] The application time of the third charge element 70 is set to 7.5 μsec, the application time of the fourth hold element 71 is set to 2 μsec, and the application time of the fourth discharge element 72 is set to 4 μsec. The application time of the fifth hold element 73 is set to 4 μsec, the application time of the fourth discharge element 74 is set to 4 μsec, the application time of the sixth hold element 75 is set to 2 μsec, and the application time of the fifth discharge element 76 is set to 4 μsec

[0072] When the middle dot waveform 15 is applied to the piezoelectric vibrator 35, the piezoelectric vibrator 35 is contracted by application of the third charge element 70, and the cavity 45 is expanded. The cavity 45 expanded as the piezoelectric vibrator 35 is expanded by application of the fourth discharge element 72 is contracted and an ink drop is jetted with the contraction of the cavity 45. The fourth charge element 74, the sixth hold element 75, and the fifth discharge element 76 are applied, whereby opposite-phase vibration is given to the meniscus for suppressing vibration of the meniscus.

[0073] Next, the placement intervals between the fine-vibration waveform 13 and the micro dot waveform 14 and between the micro dot waveform 14 and the middle dot waveform 15 will be discussed.

[0074] First, the time interval between the micro dot waveform 14 and the middle dot waveform 15 will be discussed. In the embodiment, the time interval between the micro dot waveform 14 and the middle dot waveform 15, namely, the time interval between the instant at which application of the third discharge element 68 ends and the instant at which application of the third charge element 70 starts is set to 11.5 μsec, about 1.5 times of the characteristic vibration cycle Tc of the cavity (in the embodiment, 8 μsec).

[0075] The reason why the interval between both the waveforms is thus determined is as follows:

[0076] Fig. 8 is a table to show evaluation of the record results when a one-line jetting pattern, a three-line jetting pattern, an alternat jetting pattern, and a one-line omission pattern are recorded with large dots while the time interval between the micro dot waveform 14 and the middle dot waveform 15, Tμm, is changed.

[0077] The one-line jetting pattern is a record pattern for jetting an ink drop of a large dot every eight nozzle orifices 16 as shown in Fig. 9A; the nozzle orifice 16 for jetting an ink drop is changed every given time. The three-line jetting pattern is a record pattern for selecting three adjacent nozzle orifices 16 every eight nozzle orifices and jetting an ink drop of a large dot through the selected nozzle orifices 16 as shown in Fig. 9B; the nozzle orifices 16 for jetting an ink drop are changed every given time. The alternate jetting pattern is a record pattern for jetting an ink drop of a large dot through the odd'th nozzle orifice 16 and the even'th nozzle orifice 16 alternately every given time as shown in Fig. 9C. The one-line omission pattern is a record pattern for setting a nozzle orifice 16 for jetting no ink drop every eight nozzle orifices 16 and jetting an ink drop of a large dot through the nozzle orifices 16 except the setup nozzle orifice 16 as shown in Fig. 9D. Also in the one-line omission pattern, the nozzle orifice 16 for jetting no ink drop is changed every given time.

[0078] In other words, the one-line jetting pattern is a record pattern having the lowest percentage of the nozzle orifices 16 for recording (the percentage will be hereinafter referred to as recording density) among the four patterns, and the three-line jetting pattern is a record pattern having the second lowest recording density. The alternate jetting pattern is a record pattern having the second highest recording density among the four patterns, and the one-line omission pattern is a record pattern having the highest recording density.

[0079] In Fig. 8, the evaluation results are represented by four symbols of "○," "△," "X," and "XX". The symbol "○" means that good recording can be performed with no failure, the symbol "△" means that some record failure, for example, a thick dot with wide jet pattern as compared with the normal pattern or a missing dot with jet pattern unprinted occurs, the symbol "X" means that a comparatively large number of record failures occur, and the symbol "XX" means that an extremely large number of record failures occur. Only the pattern whose evaluation result is "○" can be put to practical use.

[0080] In Fig. 8, MPBF denotes the average number of missing dot pages at the image printing time. The average number of missing dot pages means the average value from one page where a missing dot occurs to another page where another missing dot occurs when an evaluation image is recorded. For example, if the MPBF is "100," it means that a missing dot occurs about every 100 pages.

[0081] As shown in Fig. 8, in the one-line jetting pattern described above, when the time interval Tμm is 6.5 μsec, some record failure occurs, but good recording can be performed generally with no record failure.

[0082] In the three-line jetting pattern, when the

becomes hard to widen the weight range of an ink drop that can be jetted through the nozzle orifice 16. Since the record cycle is also prolonged, the record speed of the printer is also lowered.

[0094] Thus, if the time interval Tμm is set to about 1.5 times the cavity vibration cycle Tc, record failures can be prevented, the ink drop weight range can be widened, and the record speed of the printer can be increased.

[0095] Next, the time interval between the fine-vibration waveform 13 and the micro dot waveform 14 will be discussed. In the embodiment, the time interval between the fine-vibration waveform 13 and the micro dot waveform 14 and the middle dot waveform 15, namely, the time interval between the instant at which application of the first discharge element 62 ends and the instant at which application of the second charge element 64 starts is set to about 50 μsec.

[0096] It is considered that similar relation to that of the time interval Tμm between the micro dot waveform 14 and the middle dot waveform 15 also occurs for the time interval between the fine-vibration waveform 13 and the micro dot waveform 14. That is, it is considered that the timing at which a record failure occurs (failure time) appears every 8 μsec almost equal to the cavity vibration cycle Tc.

[0097] Then, in the embodiment, the time interval between the fine-vibration waveform 13 and the micro dot waveform 14 is set long to such an extent that the effect of vibration caused by the fine-vibration waveform 13 is not received. Specifically, the time interval is set to about 50 μsec, as shown in Fig. 7.

[0098] Concerning the time interval, as mentioned above, it is considered that the timing at which a record failure occurs appears every 8 μsec almost equal to the cavity vibration cycle Tc, specifically at the time interval 6.5 μsec, 14.5 μsec, 16.5 μsec, 22.5 μsec as in the case in Fig. 8. In the case in Fig. 8, the evaluation result at the time interval 22.5 μsec is "Δ" indicating such an extent that some record failure occurs; the possible reason is that vibration is attenuated as the time interval is prolonged.

[0099] Thus, if the time interval is set to 30.5 μsec (22.5 μsec plus characteristic vibration cycle of the cavity Tc), it is considered that the effect of vibration caused by the fine-vibration waveform 13 can be almost ignored. Therefore, it can be considered that the time interval between the fine-vibration waveform 13 and the micro dot waveform 14 at which vibration caused by the fine-vibration waveform 13 does not affect the micro dot waveform 14 (micro dot) is approximately 3Tc or more. In other words, the time interval between the fine-vibration waveform 13 and the micro dot waveform 14 is set to approximately 3Tc or more, whereby the effect of vibration caused by the fine-vibration waveform 13 can be eliminated and jetting an ink drop by the micro dot waveform 14 can be stabilized.

[0100] In the embodiment, the pressure generation element is formed of the comb-teeth-like vibrator 35 in so-called d31 vertical vibration mode comprising the piezoelectric body 37 and the internal electrodes 38 and 39 deposited in the direction orthogonal to the cavity pressing direction as an example; however, the invention can also be applied to a piezoelectric vibrator in so-called d33 vertical vibration mode comprising the piezoelectric body 37 and the internal electrodes 38 and 39 deposited in the cavity pressing direction and a pressure generation element using a deflection vibration mode.

[0101] The comb-teeth-like vibrator 35 in the vertical vibration mode, which is joined to the adjacent vibrator in the part on the base end side in one piece, is easily affected by crosstalk from the adjacent vibrator and a record failure easily occurs. Thus, the invention is applied to the comb-teeth-like vibrator 35 in the vertical vibration mode, whereby a record failure can be prevented more effectively.

[0102] The words "microdot" "middle dot" and "large dot" are used for describing the dot diameter in the above discussion, however, the, size of ink drops ejected from the ink recording head according to the present invention is relative and thus the size of resultant ink dot is not limited to a specific size. Namely, the present invention is not limited to the three-size dot modulation, i.e., the microdot, the middle dot and the large dot, and may be applied to any ink jet recording apparatus wherein a drive signal waveform is controlled to modulate a dot size. Especially, remarkable effect can be obtained in cases where the present invention is applied to an ink jet recording apparatus wherein the dot-size modulation is realized by utilizing residual vibration of meniscus of ink in nozzle orifices.

[0103] The aforegoing description has been given by way of example only and it will be appreciated by a person skilled in the art that modifications can be made without departing from the scope of the present invention.

Claims

1. An ink jet recording apparatus comprising:

    a drive signal generator for generating a drive signal including a first waveform component for jetting an ink drop to be a micro dot and a second waveform component for jetting an ink drop to be a middle dot;
    a pressure generating chamber communicated with a nozzle orifice; and
    a pressure generating element for varying the volume of the pressure generating chamber in accordance with the drive signal to jet an ink drop from the nozzle orifice,
    wherein an ink drop to be a large dot is jetted from the nozzle orifice when the first waveform component and the second waveform compo-

11. The ink jet recording apparatus as set forth in claim 10, the time interval is represented as a function of a natural period of the pressure generating chamber.

FIG. 2

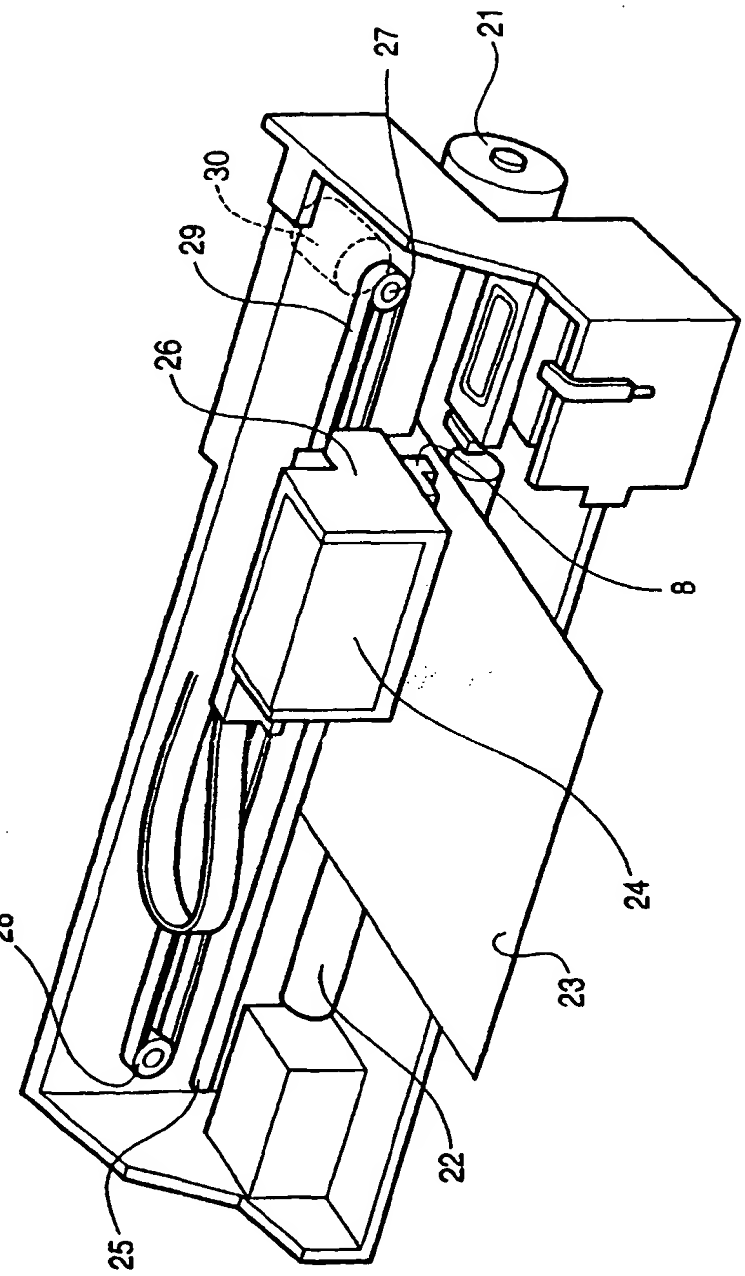


FIG. 4

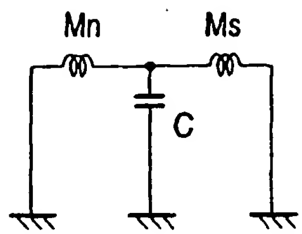
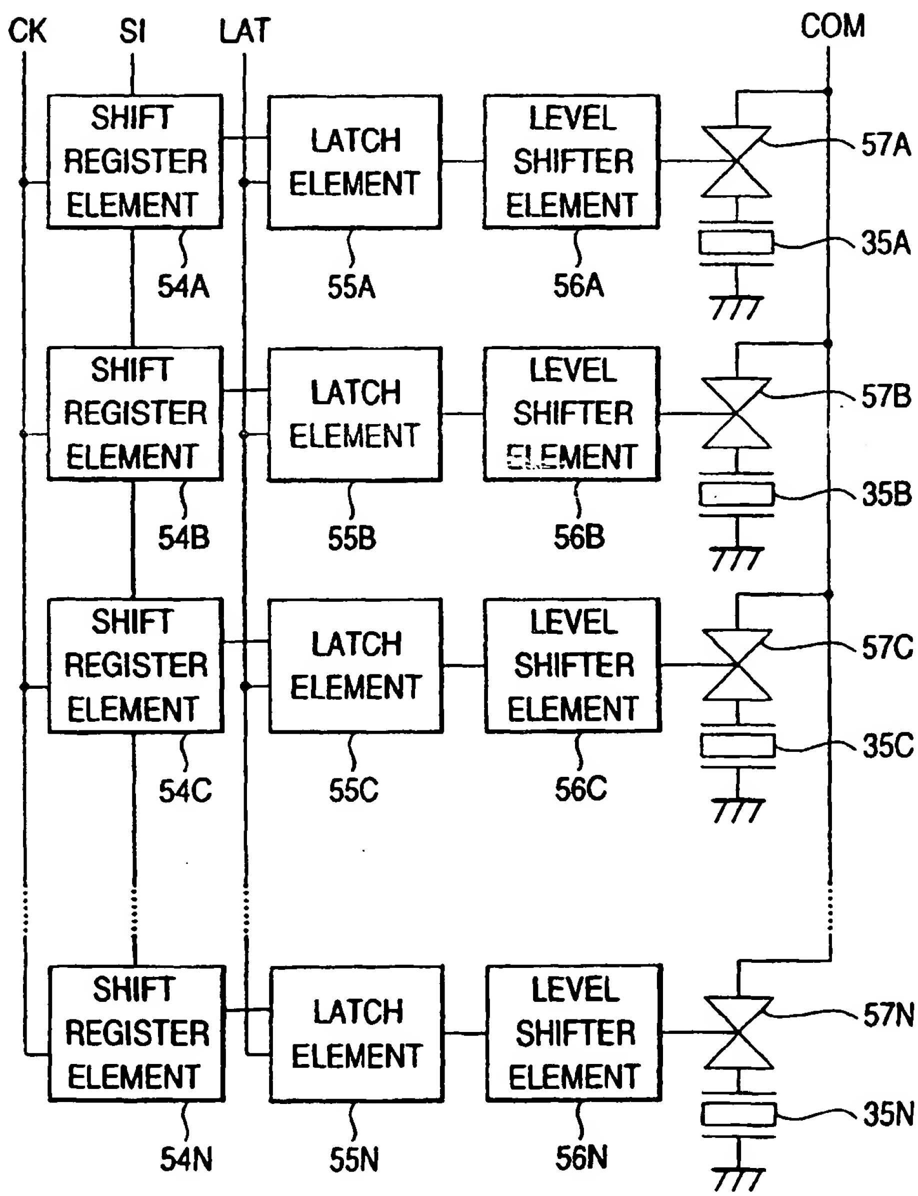

Mn
Ms
C

FIG. 5


CK
SI
LAT
COM
SHIFT REGISTER ELEMENT
LATCH ELEMENT
LEVEL SHIFTER ELEMENT
57A
35A
54A
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56A
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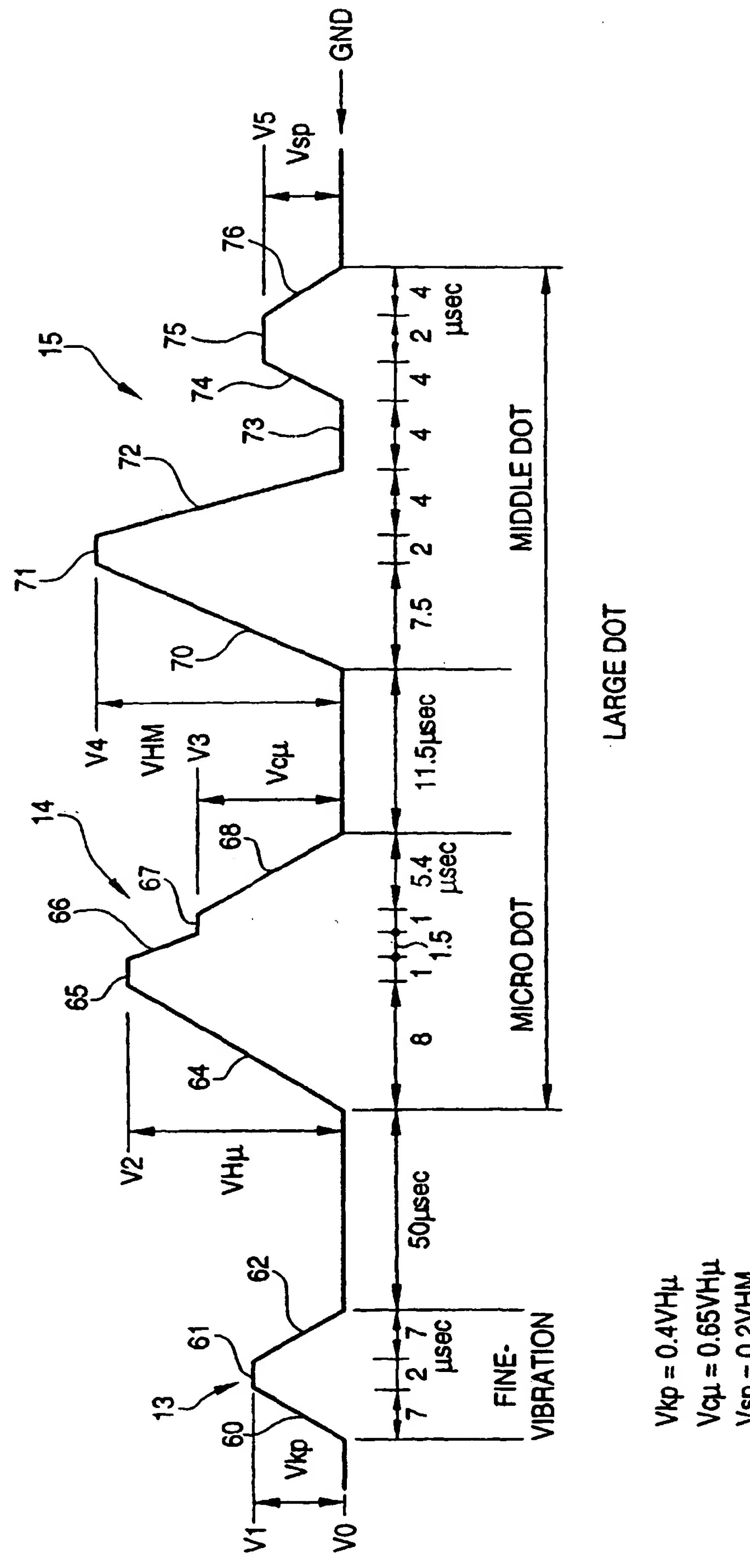
LATCH ELEMENT
LEVEL SHIFTER ELEMENT
57B
35B
54B
55B
56B
SHIFT REGISTER ELEMENT
LATCH ELEMENT
LEVEL SHIFTER ELEMENT
57C
35C
54C
55C
56C
SHIFT REGISTER ELEMENT
LATCH ELEMENT
LEVEL SHIFTER ELEMENT
57N
35N
54N
55N
56N

FIG. 7


GND
V5
Vsp
V4
VHM
V3
Vcμ
V2
VHμ
V1
Vkp
V0
13
14
15
60
61
62
64
65
66
67
68
70
71
72
73
74
75
76
7
2
7
μsec
50μsec
8
1
1.5
1
5.4
μsec
11.5μsec
7.5
2
4
4
4
2
4
μsec
FINE-
VIBRATION
MICRO DOT
MIDDLE DOT
LARGE DOT
Vkp = 0.4VHμ
Vcμ = 0.65VHμ
Vsp = 0.2VHM

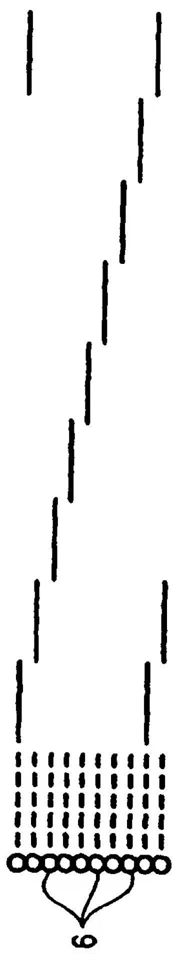


FIG. 9A

FIG. 9B

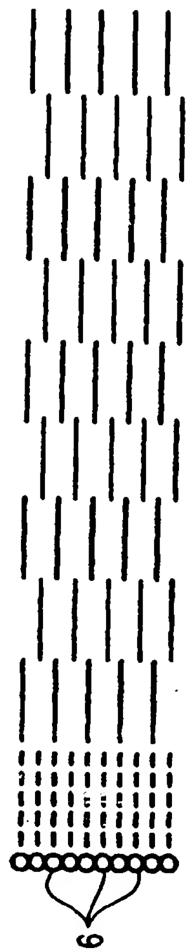


FIG. 9C

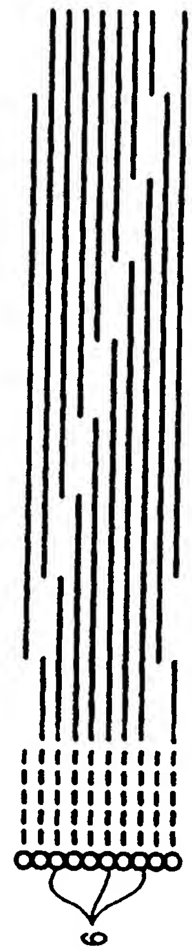


FIG. 9D

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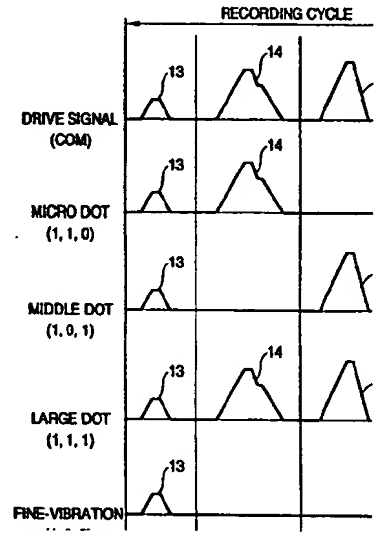
$$T\mu m = \frac{n}{2} Tc$$

here, Tc denotes a natural period of the pressure generating chamber.

FIG. 6



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